Executive Summary

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America's cities, farms, and industries are generating in excess of 1 billion tons of byproducts each year. Most of the 300 million tons of municipal byproducts (biosolids and solid residues) produced annually are placed in landfills, but the total number of landfills is decreasing. New, environmentally safe landfills that meet U.S. Environmental Protection Agency (EPA) standards are costly. While landfill disposal costs have stabilized in some areas of the country, the long-term trend is toward increasing tipping fees.

Many of our urban areas have an urgent need for long-term environmentally safe methods for recycling and disposal of byproducts. Our industries produce several hundred million tons of byproducts annually. Alternative uses have been found for a small fraction of these materials, but most byproducts are stockpiled at the site of generation or are taken to landfills. Most of our meat and other animal products are produced by large cost-effective operations in which livestock and poultry in confinement generate substantial quantities of manure annually. Accumulation of large amounts of animal, municipal, and industrial byproducts at the production site can result in degradation of soil, water, and air quality. Components of the byproducts and materials resulting from their degradation can cause odor problems. Also, greenhouse-effect gases such as carbon dioxide and methane can be released into the atmosphere, and nutrients, trace elements, and pathogens can contaminate surface water and groundwater. Currently available agronomic management practices need to be used and new management practices developed to protect environmental quality and to effectively use byproducts in agricultural production systems.

Byproduct use problems present a challenge and an opportunity for U.S. agriculture. We are currently confronted with the long-term goal of developing crop production practices that promote sustainability. Sustainable agriculture is characterized by plant and animal production practices that satisfy human food and fiber needs while enhancing environmental quality and the natural resource base. Efficient use of nonrenewable resources and on-farm resources is an important component of sustainable agriculture. Animal manure and many municipal and industrial byproducts have substantial value for agricultural use. Many of the byproducts contain essential nutrients that could meet crop requirements if applied to our land in the proper manner at the right time and in suitable amounts. Use of nutrients from byproducts could reduce dependence on fertilizers from our limited supply of mineral resources and thereby increase the sustainability of our agricultural systems. Organic byproducts can be valuable as soil conditioners and as a means of enhancing soil organic matter levels, which tend to decline with cultivation. Byproducts, byproduct compost, or mixtures of byproducts also may find specialty uses in the horticultural industry. The development of methods to optimally integrate byproduct use into sustainable agricultural practices could provide a major part of the solution to urban and industrial byproduct disposal problems.

Municipal Byproducts

The United States has reached a critical stage in the management of our two major municipal byproducts: municipal solid residues (MSW) and biosolids. Total generation of these two byproducts exceeded 325 million tons in 1995, with MSW accounting for approximately 95 percent of the total. MSW consists of a variety of components, including paper and cardboard products (approximately 35 percent by weight), yard wastes (approximately 20 percent by weight), and metals, plastic, glass, wood, and food wastes (each comprises approximately 6–9 percent by weight). The majority of MSW is placed in landfills, but the number of landfills has decreased from approximately 8,000 in 1988 to 3,200 in 1995. Thus recycling and agricultural uses of MSW are becoming preferable to landfilling.

Many of the components of MSW (paper, yard waste, food wastes, wood products) are biodegradable under proper conditions and may have potential to be used to improve agricultural and nonagricultural land. Because of limitations associated with odors, pathogens, and undesirable chemical and physical properties, new and unstable organic municipal byproducts cannot be added directly to the soil. However, composting of biosolids and selected MSW components is an effective waste management process. Composting is a self-heating microbiological process in which the decomposition of organic materials is accelerated by the growth and enzymatic activity of mixed populations of bacteria and fungi. Composting reduces the weight and volume of the byproduct while abating odors, destroying pathogens, and converting nutrients to forms that are more available to plants. As an alternative to composting, pathogen destruction and organic matter stabilization can be achieved by blending alkaline byproducts such as cement kiln dust, lime kiln dust, or coal combustion ash with biosolids. The alkaline stabilization process depends on exothermic chemical reactions to generate the high pH, heat, and drying effects needed to produce partial pathogen destruction and organic matter stabilization.

Biosolids and selected MSW components have value as biofertilizers and soil conditioners. However, these materials have relatively low nutrient contents and may need to be enriched with inorganic fertilizers to meet plant growth requirements. Municipal byproducts add organic matter to soils, thus maintaining and enhancing soil health and productivity. The EPA has developed standards, based on concentrations of trace elements and toxic organics, to regulate land application of biosolids. Currently the majority of wastewater biosolids are applied to land. Similar regulations are needed for land application of MSW components. Measures will need to be taken to segregate MSW components that may contain excess levels of toxic trace elements and hazardous organic chemicals. The fate and subsequent bioavailability of nutrients, metals, and synthetic organic residues during and after composting of MSW components will have to be determined.

Composted biosolids and MSW may have potential uses in the horticulture industry as growth media and for biocontrol of soilborne plant diseases. The safe and beneficial use of municipal byproducts in agriculture and horticulture will depend on our ability to develop products with a known and consistent range of physical and chemical characteristics. Compost quality and maturity criteria need to be developed to enhance horticultural uses of municipal byproducts. Methods need to be developed to dependably enhance the microbially mediated plant-disease suppression characteristics of compost and to reliably inoculate horticultural-grade compost with beneficial rhizosphere microbes that can biologically mediate plant nutrient uptake.

Agronomic management practices are needed to minimize the potential of land-applied municipal byproducts to degrade surface water and groundwater. Byproduct additions are generally based on nitrogen (N) requirements of the crop for the growing season. However, tests to estimate the fraction of organic N that will be converted to plant-available forms are not reliable, and N in excess of plant needs may be applied. This situation can result in leaching of nitrate to groundwater. New testing protocols are needed to allow effective management of N in municipal byproducts. Runoff of water from land amended with municipal byproducts can be a source of surface water contamination. A combination of restricted use of municipal byproducts on highly erodible land and soil conservation practices such as buffer strips and stiff grass hedges should prevent pollution of surface waters by nutrients and suspended solids from municipal byproducts.

Animal Manures

Cattle, poultry, and swine are the major sources of animal manure production in the United States. The manure (feces and urine) generated by animals raised in confinement (feedlots, dairy barns, poultry houses, and swine operations), if improperly managed, can result in significant degradation of soil, water, and air quality. There were approximately 99 million head of cattle and calves in the United States in 1990. At any one time, at least 10 million head of beef cattle are confined in feedlot operations. These animals generate 27 million tons of manure solids annually. The dairy cattle population in 1990 was 10.2 million. Dairy cattle in confinement are estimated to produce 21 million tons of solids annually. If improperly managed, the manure associated with beef feedlot and dairy operations can create significant environmental problems, including human health issues associated with contamination of surface water and groundwater.

Poultry operations in the United States produced 6.5 billion birds (chickens and turkeys) in 1990 and generated 14 million tons of litter and manure. About 90 percent of poultry manure is applied to agricultural land. Nonpoint source pollution of surface water and groundwater with N, phosphorus (P), and pathogenic microorganisms is becoming a major problem in states where the poultry industry is undergoing rapid and concentrated growth.

The farm inventory of swine tends to fluctuate between 50 and 70 million animals. Swine produce about 16 million tons of solid waste annually. Approximately 80 percent of the manure generated can be collected, stored, and spread on agricultural land. The major environmental concerns associated with storage or land application of swine manure are surface water and groundwater quality, gaseous emissions, and odors.

The animal manure generated annually in the United States contains about 8.3 million tons of N and 2.5 million tons of P. By way of comparison, about 10 million tons of N and 1.8 million tons of P are applied annually as commercial fertilizers. Animal manures are widely variable in chemical composition, physical properties, and moisture content. The nutrient content of manure varies with animal species, type of diet, growth stage and level of performance of the animal, production system used, amount of bedding material with the manure, and method of manure storage and handling. Average N, P, and potassium (K) contents in beef cattle feedlot manure are 1.9 percent, 0.65 percent, and 2.0 percent, respectively. Nutrient levels in swine manure vary with method of handling and storage but in general are lower than in cattle manure (average 0.5 percent N, 0.1 percent P, and 0.4 percent K). Poultry manure, with its relatively low moisture content and high nutrient content (4.6 percent N, 2.1 percent P, 2.1 percent K), is generally considered to be the most valuable animal manure for fertilizer purposes. The efficient conservation and use of nutrients contained in animal manures could protect environmental quality and greatly reduce the need for purchased fertilizers.

Animal manures, applied in solid, semisolid, and liquid forms, have traditionally been used as a source of nutrients for crop production. In addition, organic components of manure can build soil organic matter reserves, resulting in soils having increased water-holding capacity, increased water-infiltration rates, and improved structural stability. These changes can reduce soil loss by wind and water erosion. Soil-applied manures decrease the energy needed for tillage and reduce impedance to seedling emergence and root penetration. Manures can be used as an organic mulch when the previous crop does not produce sufficient crop residues to protect the soil surface. Manures stimulate the growth of beneficial soil microbial populations, increase microbial activity within the soil, and increase the population of beneficial mesofauna such as earthworms.

In 1990 there were approximately 330 million acres of cropland and 650 million acres of pasture and rangeland in the United States. Nationally, this provides an ample base for land application of animal manures. However, economic and environmental considerations place restrictions on the use of some land areas. Available farmland for application of manure generally exists in close proximity to most beef feedlot operations. Suitable land for safe and economical disposal of poultry manure is already a major problem in many areas of the United States. If the manure has to be transported a significant distance, transportation costs can easily exceed the fertilizer value of the manure. These economic restrictions may result in application of manure on inappropriate sites, namely those with elevated levels of N and P from previous application or those susceptible to runoff and leaching of manure nutrients and pathogens.

Environmental quality must be a major consideration when developing agronomic management practices to effectively use animal manures. Leaching and runoff of nutrients from manure at the production site and after land application can be detrimental to the quality of surface water and groundwater. Leaching of nitrate from animal manures to groundwater can be a health concern. Nitrate levels in excess of the EPA drinking water limit have been found in water wells in areas with high animal manure production and use. Runoff from production sites and fields receiving manure can pollute surface water with nutrients, pathogens, organic materials, and sediments. Phosphorus is the nutrient of primary concern from a surface water standpoint, since it is generally considered to be the limiting factor for eutrophication.

Pathogens in animal manures can be transmitted to other animals and to humans through food supplies and water. Use of animal manures in production of fresh vegetables and fruit could be a mechanism of pathogen transfer. Bacterial, fungal, and protozoan infections also have been related to manure contamination of surface water. Recent interest in this area has focused on *Cryptosporidium parvum*, a widespread protozoan parasite afflicting animals and humans. The dominant mode of transmission of *C. parvum* to humans is believed to be via contaminated drinking water and recreational waters. Although no clear-cut epidemiological cause and effect has been established, it is widely believed that farm animals are the predominant source of *C. parvum*. Dairy farms are particularly suspect as potential sources of *C. parvum* because newborn calves are readily infected and excrete large numbers of the infectious stage (oocyst) of this organism. Since many dairy operations are located near urban areas, careful management of dairy manure will be needed to prevent possible contamination of municipal water supplies. Development and use of agronomic management techniques to control runoff and erosion should enable farmers to safely use animal manures while reducing or eliminating movement of nutrients, organics, pathogens, and sediments to surface water. The Environmental Quality Incentives Program in the Conservation Title of the 1996 Farm Bill will provide cost shares and incentive payments to farmers to implement environmentally safe management of animal manures.

Animal diets are supplemented with a number of growth-promoting vitamins and minerals. The use of mineral supplements such as copper (Cu), zinc (Zn), arsenic (As), selenium (Se), and P result in elevated levels of these elements in the manure. Long-term soil application of these manures could lead to an undesirable buildup of trace elements and P in the soil. Management of soil pH will be needed to control plant uptake and food-chain transfer of Cu, Zn, Se, and As. High levels of trace elements, drug residues, and other contaminants also would limit refeeding of manure to other livestock.

Air quality has become a major environmental concern of the animal production industry. Odors generated at production and manure storage facilities constitute the most frequent source of complaints against animal producers. Uncontrolled decomposition of manure produces odorous gases, including amines, amides, mercaptans, sulfides, and disulfides. Ammonia volatilization from manure creates an odor problem and may contribute to acid rain. These noxious gases can cause animal respiratory diseases. Greenhouse-effect gases such as carbon dioxide, methane, and nitrous oxides also are released from manure handling and storage facilities. Improved manure handling and storage methods are needed to reduce emission of these gases.

Current manure management practices are not designed to effectively conserve and use animal manure nutrients. Nitrogen is the nutrient most susceptible to loss (primarily through ammonia volatilization) after manure excretion and during storage, transport, and land application. Because of these losses, less than 25 percent of the N originally present in the manure may be available for crop production. Swine manure can lose up to 90 percent of its N through ammonia volatilization in anaerobic storage lagoons. Because of these N losses, N:P ratios in manure are generally lower than crop needs, resulting in buildup of excess P in soil. Rapid tests to determine nutrient content and release rates from manure are needed so farmers can apply manure at rates that will supply crop needs. Improved handling, storage, application, and analysis methods need to be developed to effectively use animal manures for enhanced crop production while avoiding environmental degradation.

Industrial Byproducts

A number of industrial byproducts including residues from coal combustion, fertilizer production, the construction industry, and incineration are produced in substantial amounts throughout the country. Many of these byproducts have potential for use in agriculture, but they have not been thoroughly investigated or they have changed in composition as a result of new technology. Coal combustion byproducts are emphasized in this report because their production is rapidly increasing, coal combustion technology is changing, and disposal of byproducts from coal combustion is becoming a major issue.

Combustion of coal produces a variety of byproducts including fly ash, bottom ash, flue gas desulfurization (FGD) residue, fluidized bed combustion (FBC) residue, and coal gasification ash. Total production of coal combustion byproducts was 120 million tons in 1991, with production expected to increase to 170 million tons annually by the year 2000. Fly ash, the major byproduct from coal combustion, is the particulate residue that enters the flue gas stream and is either collected by emission control devices or released to the atmosphere. Bottom ash is the residue that remains in the boiler after coal combustion. FGD and FBC residues are byproducts from technologies used to reduce sulfur (S) emissions from coal combustion. FGD byproducts result from post-combustion treatment of flue gases with absorbent (calcium oxide, limestone, dolomite) to reduce SO_x discharge to the environment. FBC involves removal of SO_x during combustion of a finely divided mixture of coal and limestone on a fluidized bed created by injection of air. Production of FGD and FBC byproducts will increase to greater than 50 million tons annually by the year 2000 as a result of Clean Air Act requirements for reduced S emissions.

Currently about 20 percent of the ash byproducts are recycled. They are used in the construction industry as fill material and as components of other products such as concrete, cement, and asphalt. FGD byproducts are used to a limited extent in the production of sulfur-related chemicals and wallboard. Approximately 80 percent of coal combustion byproducts are retained at the power plant site. Storage techniques include surface impoundments, landfill placement, and placement in mines and quarries. Regulatory barriers to land application and relatively inexpensive on-site disposal have discouraged widespread agricultural use of coal combustion byproducts to date. Potential environmental problems associated with on-site storage and the ever-increasing amount of byproducts are making agricultural use more attractive.

Land application of selected coal combustion byproducts can bring about favorable changes in soil chemical and physical properties. Many of the byproducts are alkaline in nature and can be used as liming materials to increase soil pH. Although coal combustion byproducts are low in N and P, they can serve as a source of other plant essential nutrients, including calcium (Ca), boron (B), molybdenum (Mo), S, Cu, and Zn. Fly ash, alone or in combination with municipal biosolids, has been successfully used to reclaim acidic mined land. FBC byproducts and oxidized FGD materials contain significant amounts of gypsum. Surface applications of gypsum have been shown to be effective in ameliorating subsoil acidity. Byproducts high in gypsum also can improve soil structure, increase water infiltration, and reduce mechanical impedance to root growth.

Plant growth limitations, food chain transfer of trace elements, and water quality issues are among the problems that may be associated with agricultural use of coal combustion byproducts. Many coal combustion byproducts have a high pH and high levels of soluble salts that can severely inhibit plant growth. The most serious potential trace element hazards associated with agricultural use of coal combustion byproducts appear to be B, Se, As, and Mo accumulation in soils and plants. Excessive application rates of byproducts containing high levels of these elements could result in phytotoxic levels of B and elevated levels of As, Mo, and Se in plant tissue. Many FGD byproducts contain appreciable amounts of calcium sulfite. When initially added to soils, calcium sulfite can inhibit plant growth. Fortunately calcium sulfite is rapidly oxidized to calcium sulfate in soil systems. Therefore, if this oxidation can be completed prior to crop planting, it may be possible to add coal combustion byproducts that are high in calcium sulfite directly to soils.

Information is needed about the benefits and risks associated with agricultural use of the new-technology coal combustion byproducts. It is difficult to generalize about characteristics of a particular coal combustion byproduct because chemical and physical properties of these materials depend on a number of factors, including power plant design, operating parameters, sources and types of coal consumed, and types of reactive reagents used in the FGD process. Those coal combustion byproducts with significant amounts of gypsum seem to be most suitable for agricultural uses. More information is needed about the behavior in soils of FGD byproducts containing high levels of calcium sulfite.

In addition to coal combustion byproducts, three other broad classes of industrial byproducts were examined in this report: residues from the P fertilizer industry, residues from construction trades, and incineration ashes. Two byproducts from the phosphate fertilizer industry—phosphogypsum and calcium silicate slag—have some favorable properties for agricultural uses. Phosphogypsum is a byproduct from the production of phosphoric acid from phosphate rock. Approximately 40 million tons of this material are produced in the United States each year. Phosphogypsum has been used in agriculture as a Ca and S nutrient source and as an amendment to ameliorate subsoil acidity. The EPA has disallowed agricultural use of phosphogypsum sources with radium-226 radioactivity in excess of 10 $pCi\ g^{-1}$. This ruling has essentially eliminated the use of phosphogypsum from southern Florida but allows use of phosphogypsum produced from sources of phosphate rock with lower radium-226 activities. Calcium silicate slag is a byproduct of electric furnace production of phosphate fertilizer from phosphate rock. This byproduct has value as a liming material and contains plant nutrients. Silicon in the material has been shown to enhance sugarcane resistance to foliar ringspot disease.

The construction trades generate several byproducts with potential agricultural uses, including aggregate industry fines and concrete manufacturing residues. Annual production of sand, gravel, and crushed stone results in approximately 100 million tons of waste fines. Weathering of the mineral phases in the aggregate fines should serve as a slow-release source of plant nutrients. The aggregate industry fines could be mixed with organic residues to create an artificial soil. Approximately 10 million tons of concrete manufacturing residues are generated each year in the United

States. This material is alkaline and has a high content of calcium silicate. The material should be useful as a liming material and would be expected to have some common characteristics with calcium silicate slag. Additional research is needed to characterize benefits and risks associated with agricultural use of these two materials.

Production of ash from combustion of wood waste and the incineration of MSW is increasing. Most of the incineration ash currently is being placed in landfills. This material is likely to be quite variable in composition, particularly in regard to trace element levels. Potential problems with elevated trace element levels in incineration ash probably will preclude its use in agriculture. The combustion of wood waste to produce steam or electricity creates localized sources of ash. Between 1.5 and 3 million tons of wood ash are produced annually. Wood ash generally has value as a liming material and as a source of nutrients. Wood ash should not pose an environmental risk if it is applied to the soil at lime requirement rates.

Research Needs

Investment in research and education will be needed to increase and improve agricultural use of municipal, animal, and industrial byproducts. Additional research in the following areas will ensure efficient and environmentally safe uses for a variety of readily available byproduct materials:

1. Treatment methodologies and management practices need to be developed to minimize loss of nutrients from manure and other byproducts during handling and storage. A substantial portion of the N initially present in manure and in some municipal byproducts can be lost during aerobic composting and through ammonia volatilization, denitrification, leaching, and anaerobic decomposition in lagoons. Liquid wastes such as liquid manure and wastewater from animal operations require development of special treatment methodologies. Improved systems for nutrient capture, immobilization, or recovery should help conserve nutrients during handling and storage until byproducts can be beneficially applied to land.

2. A greater understanding of nutrient and trace element transformations and reactions in byproducts and in soil treated with byproducts is needed. This information will allow systems to be designed to conserve nutrients during byproduct handling and storage. This information also is necessary to predict the environmental fate and bioavailability of nutrients and trace elements in byproducts.

3. Improved nutrient management tools are needed to prevent excess nutrient and trace element buildup in soil from land application of byproducts. Rapid and effective analytical methods are needed to estimate concentrations of bioavailable nutrients and toxic components in byproducts and soils amended with byproducts. The question of basing byproduct application rates on either N or P needs to be resolved. Tests for soil threshold levels of N and P for the purpose of protecting water quality need to be developed, assessed, and used to identify areas at risk from further byproduct application. Improved nutrient management practices will help farmers select byproduct application rates that keep nutrient concentrations within beneficial ranges, avoid contamination of our waters, and facilitate loading rates that are cost effective and timely.

4. Management practices need to be developed to protect surface water and groundwater from nutrients, trace elements, sediments, and pathogens in byproducts applied to land. A variety of management techniques, including vegetative buffers, wetlands, riparian zones, drainage management, and cover crops need to be assessed over a range of conditions to determine where they can be effectively applied to protect water quality and where their use would be inappropriate. Effective methods to remediate sites with excess nutrients and trace elements, including removal with plants and deactivation with industrial and municipal byproducts, need to be developed.

5. Methods of incorporation and surface application of organic byproducts to increase organic matter levels in soils without degrading environmental quality should be evaluated. Many of our soils have lost organic matter through erosion of topsoil and tillage-accelerated biological oxidation. Benefits associated with enhanced soil organic matter levels include protection from erosion, increased water infiltration rates, higher available water holding capacity, increased plant rooting depth, and enhanced supply of nutrients.

6. A careful assessment must be performed to determine the risks associated with trace elements, synthetic organics, and pathogens in byproducts applied to land. A risk-assessment pathway approach similar to that used to develop regulations for land application of municipal biosolids is needed for animal manures and other byproducts. EPA has established regulations for levels of trace elements, synthetic organics, and pathogens in biosolids, including regulations for cumulative amounts of these components that can be applied to land. Appropriate regulations for land application of animal manures and other byproducts is needed to allay public concerns about the agricultural use of these materials.

7. Effective control of odors from manures and other byproducts at handling, storage, and processing facilities is needed. Odors generated at these facilities create air quality problems and public relations difficulties, especially in urban areas. The basic microbial processes involved in odor formation need to be understood and linked to management practices geared to preventing odor generation during handling, storage, and use of byproducts and to preventing escape of odors.

8. Animal use of nutrients and dietary supplements in animal feed must be improved. More efficient conversion of feed to meat and other animal products can reduce the amount of manure produced and lower nutrient levels in the manure. Methods are needed to improve the use of P in grain by poultry and swine, thereby reducing the need for supplemental P additions to feed. Careful use of animal drugs and dietary supplements such as Cu, Zn, As, and Se can limit concentrations of these components in the manure, therefore making it a more valuable product for soil application or animal refeeding.

9. Byproduct quality and consistency needs to be improved to increase the desirability of these materials for agricultural and horticultural uses. The composition of many byproducts is not consistent over time. The use of composting to stabilize organic byproducts and convert them into fertilizers and soil conditioners is likely to increase, but quality and maturity criteria need to be developed. A known and consistent range of allowable physical and chemical characteristics of compost and other byproducts is needed to develop safe and beneficial uses of these materials.

10. Methods for co-utilization of municipal, animal, and industrial byproducts need to be identified and developed. Products with enhanced value and utility for agricultural and horticultural uses can be developed by mixing, blending, or co-composting different byproducts. Byproducts may need to be co-utilized to overcome problems in the materials themselves or to overcome soil problems. This approach can be used to eliminate pathogens and toxins, reduce availability of toxic trace elements, and enhance nutrient availability. Examples of this approach include stabilization of biosolids using alkaline byproducts and the reclamation of mined land with fly ash and municipal biosolids.

11. Alternative uses of manures and other byproducts need to be investigated and developed, especially in areas where land application of these materials can cause significant environmental risk. Many byproducts have potential for energy production through burning, methane generation, or conversion to other fuels, but these processes need to be developed and optimized. Manures and other byproducts such as food industry wastes, when properly used, have greater value as an animal feed than as a soil amendment. Development of methods such as composting or pelletizing to reduce the weight, volume, or form of manure and other byproducts could reduce transportation costs and open up alternative uses.

12. A national database is needed on major municipal, animal, and industrial byproducts. This database should include such details as amounts produced, geographic distribution of production, and the physical and chemical properties of each material. It should be designed to facilitate Geographical Information System (GIS) layering of the various data sets. A range of values for agronomically important parameters such as pH, nutrients, and toxic trace elements will facilitate selection of byproducts that will benefit the soil-plant system and identify those that should have restricted use. This database also will contribute to the development of models and decision-support systems for effective and environmentally safe use of byproducts.

13. Economic analyses of costs and benefits of potential byproduct management practices are needed. Economic viability is an essential component of sustainable byproduct management systems. For certain byproducts, the producer and the public may need to share costs with the farmer. Tradeoffs between farm income and environmental impacts need to be assessed. This approach allows selection of the most profitable byproduct management system to meet state and Federal regulations.

14. Decision support systems need to be developed to optimize land application of byproducts. These systems will need to incorporate recent information about byproduct materials, most effective agronomic management practices, and economic considerations. Decision-support systems should provide farmers, extension agents, farm management consultants, and Natural Resources Conservation Service personnel with a powerful tool to ensure effective use of byproduct materials while preserving environmental quality.

15. Regulations must be developed that allow the use of beneficial byproduct materials and yet protect the environment and human health. Environmental regulations developed and interpreted by individual states currently constitute one of the main barriers to increased land application of these materials. Regulations developed using sound scientific data will help overcome current barriers to agricultural use of byproducts posed by state regulations that are excessively restrictive and that may not have a sound scientific basis.

As the real advantages associated with careful agricultural use of byproducts are determined and hazards are defined and controlled, efforts will be needed to convey this information to the agricultural community and the public. Successful handling of the byproduct disposal problem will require a partnership between the urban and agricultural sectors. The agricultural sector will need to know which byproduct materials can be applied to land, how much can be applied, and which methods of application are environmentally safe. The public will need to be convinced that agricultural use of byproducts is environmentally safe and cost effective and does not pose a human health risk. Byproduct producers and the public may have to pay additional fees to make the use of byproducts more attractive to farmers. Byproduct transportation expenses may have to be subsidized, and additional steps may be needed at the production site to make products more valuable for agricultural and horticultural uses. These expenditures, however, may be small compared to increasing costs of current byproduct management practices and the potential benefits to be gained through environmentally safe use of byproducts in agricultural operations.